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Improving aerodynamic characteristics for drag reduction of heavy truck

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Abstract. Significant increasing vehicle performance can be achieved by reducing aerodynamic drag because of rising average speeds and reducing fuel consumption. Russian truck manufacturers do not prioritize the truck aerodynamic issues, therefore majority of existed models has a very high value of drag coefficient, and moreover, vehicles older than 10 years predominate in operation. In this regard, against the background of rising prices for liquid fuel, the reduction in aerodynamic drag allows to solve the problems posed. The article presents the results of a study of the aerodynamic drag coefficient for KAMAZ heavy truck when using a set of cab fairings of different shapes. Using the software, the analysis of the influence of the shape of the fairing on the coefficient of air resistance of the car is made. As a result, fuel economy is calculated taking into account the selected optimal cab fairing and cab−side extenders from the aerodynamic drag coefficient

1. Introduction

One of the priorities in the automotive and transport industries is reducing fuel consumption and increasing average vehicle speeds. Analysis of car aerodynamics is crucial in increasing environmental friendliness of the cars, since it allows you to get fuel economy at the same engine power and increase the maximum speed of the vehicle by reducing the air resistance. The aerodynamic drag depends on vehicle velocity in a quadratic relationship and is often not taken into account at low speeds, because of which Russian truck manufacturers have not been taking into consideration such a design stage as the development of the cab shape.

Currently, technologies allow heavy road vehicles to develop higher speeds, therefore, the issue of improving aerodynamic properties becomes more relevant. Aerodynamic drag is the cause for more than two-thirds of the fuel consumption of large trucks at highway speeds, moreover, in 2018, the share of road transport freight amounted to 67%, significantly exceeding the shares of rail, air and water transport. Taking into account the amount of liquid fuel have been consumed by domestic trucks and their annual mileage, it can be concluded that they are the main consumers of liquid fuel. Therefore, the issue of reducing fuel consumption is so often raised by domestic and foreign researches. So A N Evgrafov in his study highlighted the significant influence of truck aerodynamics on fuel saving. In [1, 2] the author provides data on experimental studies of the shape and parameters of the car body, produced at AVTOVAZ, focusing on the fact that changing the car body shape from LADA-2105 to LADA-2110 allowed to reduce the drag coefficient by 36%. In the article are described the main ways to reduce the aerodynamic drag of passenger cars. Further, the author asserts the expediency of reducing air resistance study of heavy vehicle tractor-trailer trucks, citing experimental data on reducing fuel consumption for MAZ and KAMAZ vehicles by installing fairings.

According to [2], aerodynamic properties analysis takes an important place in the problem solving process of improving the fuel efficiency of vehicles. Possibilities for drag reduction of heavy vehicles are limited by the requirement that the basic function of the vehicle should not be compromised, so it is not possible to achieve an ideal aerodynamic shape for a truck, but there are several points that most European trucks manufacturers aim to apply, for example, the absence of non-rounded edges, a high streamlined roof that completely covers the trailer. Using cab shaping, deflectors mounted to the cab, fairing on the front and end sides of the trailer, extenders, rounding of the front edge of the body, side skirts for the trailer can be considered as controlling flow method and reducing turbulence (figure 1).

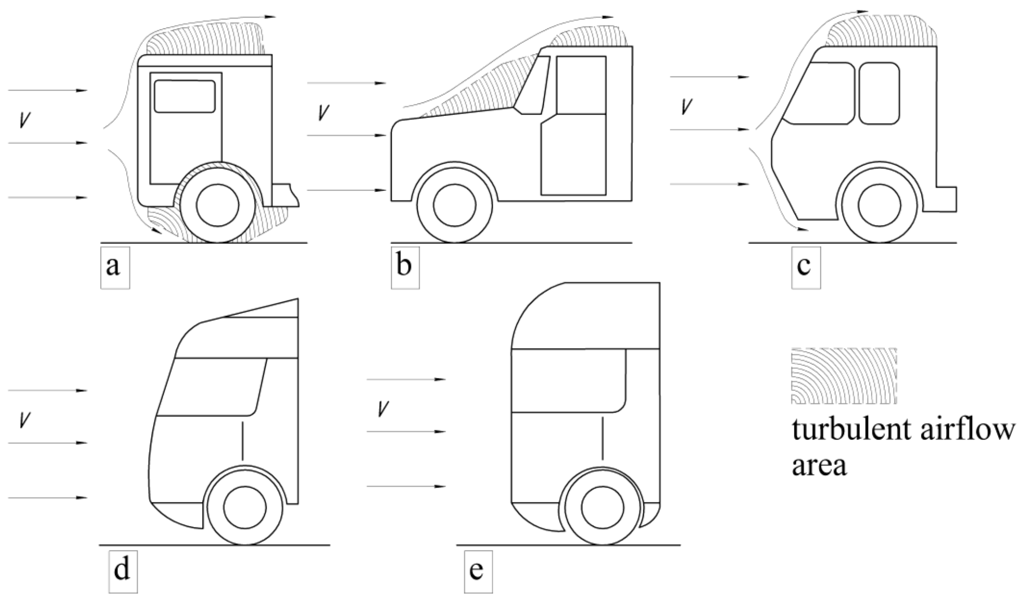

Figure 1. The influence of the truck cab shape on the formation of air turbulent flows.

The studies [3, 4, 5] have shown that aerodynamic properties of heavy vehicle tractor-trailer trucks can be improved, since they have insufficiently streamline body shape, the gap between the tractor and the trailer, and turbulent flow in the area of underbody and wheels.

Despite the gradual improvement in the shape of the cab and body, external aerodynamic devices are more popular for reducing aerodynamic drag among automotive manufactures. Installation of such elements allows significantly reducing aerodynamic drag of heavy vehicle tractor-trailer trucks without changing the main forming elements of the cab without large investment.

Currently, many researchers consider the influence of add-on devices on aerodynamic performance of heavy trucks, analyzing the influence of the shape [6, 7], material, method of installation of these elements and reducing the total air drag coefficient [8, 9, 10, 11], this could allow to reduce the fuel consumption keeping the average speed of heavy vehicle. Therefore, in this paper will be considered the simulation of a set of fairings for the cab of KAMAZ car, followed by an estimation of drag coefficient and reduction of fuel consumption.

2. Numerical methods for the study of car aerodynamics

The aerodynamic drag force P_w of a body moving in the air is determined by the air drag coefficient C_x, the area of the frontal section A_f, the air density and the speed of the air flow q. Since aerodynamics is

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similar to hydromechanics, the aerodynamic drag force is calculated using the following formula derived from the basic statements of hydromechanics:

$$P_w = C_x * q * A_f \tag{1}$$

$$q = \frac{1}{2} * V^2 * \rho, \tag{2}$$

where V is the flow rate;
ρ – air density.
Then the drag coefficient Cx can be found by the formula:

$$C_x = \frac{P_w}{\frac{1}{2} * V^2 * \rho * A_f} \tag{3}$$

At present, numerical methods are increasingly used for testing vehicles, and the results obtained in this way have minor discrepancies with full-scale experiments, which is confirmed by the conclusions in [12, 13, 14]. The use of modern modeling methods can allow optimizing the parameters of vehicles with less material and timing resources compared to full-scale testing methods.

The use of modeling methods in the aerodynamic properties study is circumstantially discussed in [15], the main stages of tests using numerical methods are given, and the accuracy of the results obtained is evaluated. The study of the car body and trailer shape influence using finite element methods and mathematical modeling is given in [16, 17]. The influence of certain elements of the truck exterior on the aerodynamic drag force is considered in the article [18].

A lot of numerical and experimental studies about the heavy vehicle aerodynamics have been carried out. The analysis of domestic and foreign studies has shown that the using numerical methods for considering the aerodynamic properties of trucks allow obtaining results with sufficient accuracy. In this article, the influence of the cab fairing shape on the drag coefficient of the KAMAZ car will be determined using computer modeling.

3. Computational model

To study the aerodynamic properties, a 3D model of the KAMAZ-65117 car with a total mass of 24,000 kg was built (figure 2a). Since the flow around a truck is a complex aerodynamic process, which includes both laminar and turbulent flows, it is not possible to fully take into account all aerodynamic processes during modeling. Several assumptions were made: the built model includes only the main and largest structural elements, small elements of the car's structure, gaps and transitions of the body parts surfaces with a size less than 30 mm are excluded.

Then, based on the analysis of the fairings shape, given in the articles [1, 2, 3, 19], several 3D models of fairings were created with the most significant influence on the aerodynamic drag force. After carring out computer modeling, the option was chosen in which the drag coefficient is the lowest and only this option is considered in the work.

The difference between the height of the cab and the awning is 1.05 m. to reduce the angle of inclination of the upper part of the fairing, it is planned to install it from the beginning of the hatch in the cab, but with a hole provided in the fairing for it (figure 2b). The trailer will be covered with cab fairing not only from the top, but also cab-side extenders are mounted from left and right sides.

During the simulation, the option of installing deflectors to reduce turbulence under the cabin was considered, but this modification had little effect on the overall drag coefficient, so it is not given further in the work.

4. Air flow simulation and results

The simulation was performed in Solidworks 2016, the Flow Simulation module, which is intended for solving the problems of hydrodynamics in the CAD package interface. This fact greatly simplifies

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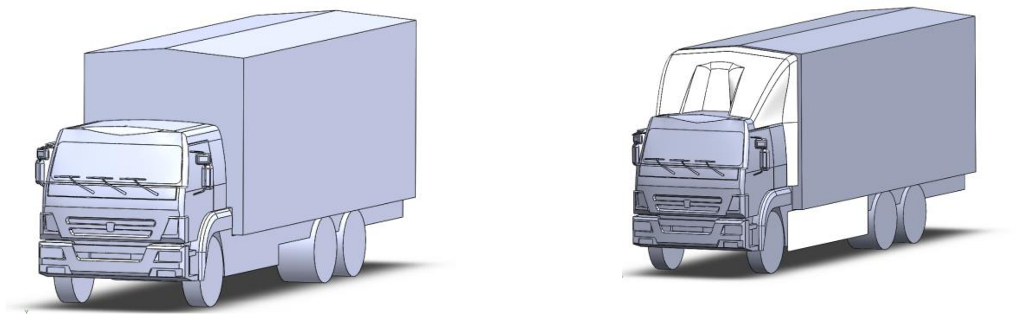
manipulations with the calculated geometry and generally reduces the time to prepare the computational model.



a *b*

Figure 2. Model of the KAMAZ-65117: *a* - 3D model of the KAMAZ-65117; b - 3D model of the KAMAZ with cab fairing and cab-side extender.

The Flow Simulation module uses the Navier-Stokes equations, and the k-ε turbulence model is used to close them [20].In addition to "standard k-ε Model", the realizable k-ε model incorporates certain mathematical constrains on the normal stresses, consistent with the physics of turbulent flows This model has high accuracy for solving external flow tasks [21], that is relevant for solving optimisation truck aerodynamic problem. Also, the advantages of the selected CAE module include the use of a rectangular (Cartesian) mesh. This mesh avoids the difficulty of splitting the calculated areas and significantly reduces the time of its construction, also, it is possible to achieve the required accuracy with fewer elements (compared to unstructured mesh) [21].

The method of determining the drag coefficient is to find the aerodynamic drag force acting on the body when it flows around the incoming flow. The resistance force of the incoming flow is determined automatically by Flow Simulation based on the pressure fields on the surface of the streamlined vehicle body. Based on this, the pressure convergence is used as the solution criterion. In addition to the aerodynamic drag force, air streamlines are visually processed to localize and further eliminate turbulence zones.

The following parameters were taken as initial data: vehicle velocity V=60 km/h, ambient temperature 293 K, air density 1.204 kg/m3, Pressure 101325 Pa. The design area for solving the problem of external aerodynamics is a model of the volume of air enclosed between the walls of a flat channel and the model of a truck.

Figures 3 and 4 show the results of the simulation: the streamline for flow over vehicle and the pressure of the air environment on the car, based on which the drag coefficient for the base model is obtained 0.809. The estimated aerodynamic drag force is 1179 N.

Figure 3. The streamline for flow over KAMAZ vehicle.

Enlarging the area near to the cab (figure 4), it can be noticed the turbulent flows between the cab and the trailer. The front of the cab causes the most significant resistance and creates an area of high pressure in front of it. An area of low pressure is formed above the top of the trailer, and the area in front of the trailer is an area of high pressure, which is associated with high resistance to airflows (figure 5).

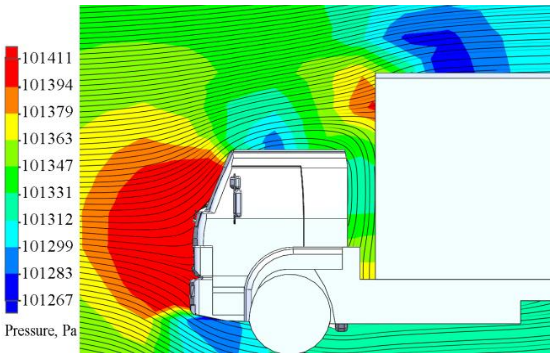


Figure 4. The streamline for flow over KAMAZ cabin.

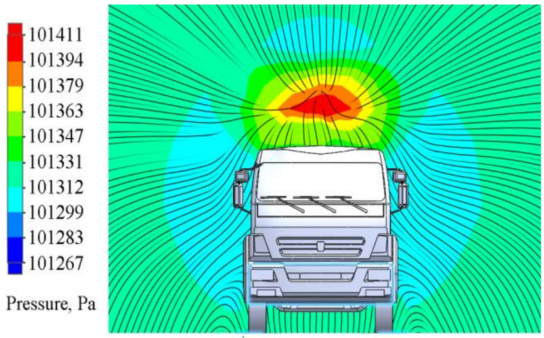


Figure 5. The streamline for flow over KAMAZ cabin (front view).

After conducting similar studies of the aerodynamics of a car with fairings installed on it, the following results are obtained (figure 6): the turbulence between the cab and the trailer occurs from the wheels, the most significant resistance is caused by the cab frontal part, the area of increased pressure in front of the trailer is significantly reduced, there is an area of reduced pressure between the cab and the awning. With a total aerodynamic drag of 953 N, the drag coefficient is 0.654.

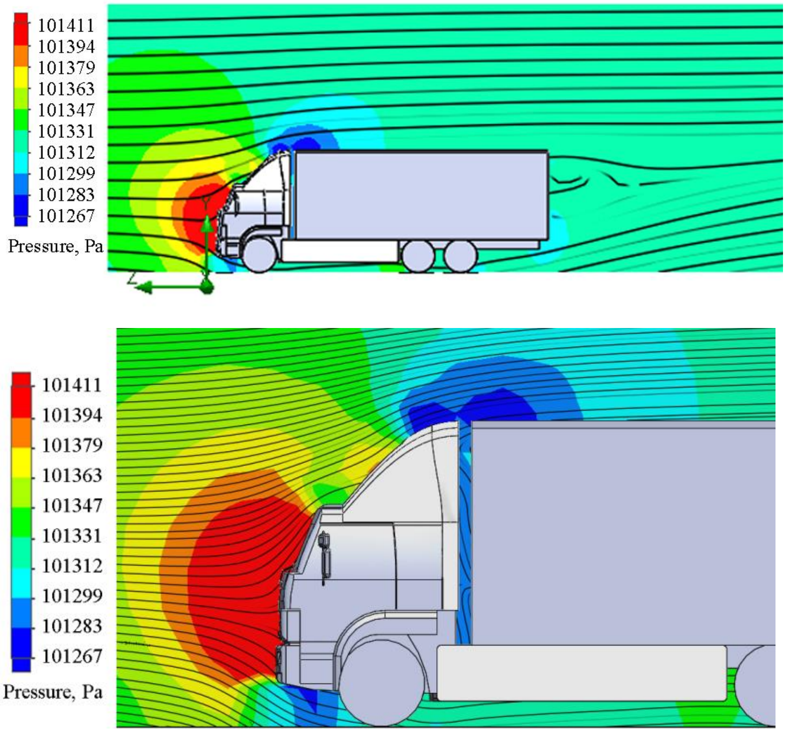


Figure 6. The streamline for flow over KAMAZ cabin after assembling of fairing and cab-side extender.

5. Conclusion

The results, which obtained in the course of the study, showed that the using of cab fairings on KAMAZ heavy truck can significantly reduce the force of aerodynamic drag by reducing the drag of the trailer. The applying of numerical modeling methods makes it possible to estimate with sufficient accuracy the streamlined shape of the cab and body of the vehicle at minimal cost. An analysis of the aerodynamic properties of various shaped cabin fairings conducted in the Flow Simulation environment allowed us to select a variant for which the drag force was reduced by 19.1%.

Thus, reducing the aerodynamic drag will reduce the fuel consumption of the car. The calculations showed that at a speed of 60 km/h, the fuel consumption of a fully loaded car will decrease by 1.54 l / 100 km, that is, by 5.1%, at a speed of 90 km/h, the fuel economy will be 3.34 l/100 km or 9.86%. As a result of testing a car with a set of fairing, skirts and deflectors installed on it in the conditions of driving on the highway, the results were obtained: at an average speed of 60 km/h, fuel consumption decreased by 1.2 l / 100 km (4.4%), and at an average speed of 90 km/h, fuel consumption decreased by 3.15 l/100 km (9.31%).

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